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(54) Porous calcium phosphate ceramics for in vivo use

Poröse Calciumphosphat-Keramik für in vivo-Anwendungen

Céramique poreuse à base de phosphate de calcium pour utilisations in vivo

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DescriptionBACKGROUND OF THE INVENTION

5 Field of the Invention

[0001] The present invention relates to a porous calcium phosphate type ceramics, and, particularly, to a ceramics for in vivo use such as artificial bones, fillers for bones and cell culture supports, which is suitable for the purpose intended to fix and support cells and to allow these cells to grow and to be cultured.

10 Description of the Related Art

[0002] A calcium phosphate type ceramics has no harmful action on a living body and a tendency to replace for natural bones. It is therefore a preferable material as artificial bones.

[0003] However, a current calcium phosphate type ceramics used for artificial bones has large strength but involves a difficulty in fixing cells in the case where it is produced as a densified body. Also, when it is produced as a porous body, it allows cells to enter it, but it has less strength and therefore tends to be handled with difficulty.

[0004] As a method of applying such a calcium phosphate type ceramics, there is the idea that the strength is improved to a limited extent, and many cells are made to be fixed as early as possible and to grow proliferously to thereby promote the formation of bones by the power of the cell itself whereby intending to make an early recovery.

[0005] US 4,654,314 discloses a porous ceramic material composed of a sintered porous body of a calcium phosphate compound, wherein a multiplicity of capillary void paths having a diameter of 1-30 µm and a multiplicity of pores having a diameter of 1-600 µm are formed. The pores are at least partially connected to the exterior space of the sintered body through at least a part of the capillary voids. The ceramic material is suitable for inducing new-born bone, controlling resorption of bone with age and remedying bond defects.

[0006] DE-A1-100 18 394 discloses a porous calcium phosphate sintered body comprising spherical pores having a diameter of 150 µm or more, which are interconnected with each other through communicating portions having a diameter of 50 µm or more. The porosity of the sintered body is 55-90 %.

30 SUMMARY OF THE INVENTION

[0007] The present invention is preferably used in such an application method and provides a ceramics for in vivo use which allows cells to intrude thereinto easily and to be fixed easily, with the result that an early recovery and the like are expected.

[0008] First, the raw material of the calcium phosphate type meant in the present invention is preferably, although not particularly limited to, any one of hydroxyapatite, apatite carbonate and tricalcium phosphate or mixtures of two or more of these compounds or those containing one or more of these compounds as main component. Also, the tricalcium phosphate is preferably those having a β-phase in view of strength.

[0009] According to the present invention there is provided a calcium phosphate type porous ceramics for in vivo use, comprising pores (1), (1a) having an almost globular form, which are contacted and communicated with each other so that the ceramics has a permeability of 1.48×10^{-8} to $78.96 \times 10^{-8} \text{ m}^2$ (150-8,000 centidarcy), measured according to ASTM C577-68, and the ceramics further complies with either one or both of the following two requirements:

- 45 (i) the volume of the pores (1) communicated with a communicating portion (2) having a hole diameter (D_2) of 8-20 µm is 2-18% of the volume of all pores, and
- (ii) the volume of the pores (1a) having a pore diameter of 8-15 µm is 0.5-15% of the volume of all pores.

[0010] According to the present invention a calcium phosphate type porous ceramics as defined above is preferred, wherein both requirements (i) and (ii) are fulfilled.

BRIEF DESCRIPTION OF THE DRAWINGS**[0011]**

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Fig. 1 is an enlarged sectional view showing one embodiment of a ceramics for in vivo use according to the present invention; and

Fig. 2 is an enlarged sectional view showing another embodiment of a ceramics for in vivo use according to the

present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

- 5 [0012] In the present invention, the permeability which can be measured relatively simply using a method which has been surely established and indicates the penetrability of gas is designed to fall in a specified range and/or each proportion of the pores having a pore diameter or communicating pore diameter falling in a specified range in all pores is designed to fall in a specified range, thereby making the ceramics suitable to the intrusion of cells such as osteogenetic cells into a material for in vivo use and making it easy to fix the intruded cells. In the following the present invention will be explained.
- 10 10 [0013] In an enlarged sectional view of Fig. 1, this ceramics for in vivo use comprises a calcium phosphate type porous sintered body, has no harmful action on a living body and has relatively high strength even if it is porous. Also, the ceramics has a good many of almost globular pores 1, in which these pores 1 are in contact among them to form a communicating portions (holes) 2. The permeability (transmittance) is designed to be $1.48 \cdot 10^{-8} \text{ m}^2$ or more and $78.96 \cdot 10^{-8} \text{ m}^2$ or less (150 centidarcy or more and 8000 centidarcy or less) by setting the hole diameter D_2 of the communicating portion (hole) 2, by selecting the number of the communicating portions.
- 15 [0014] Namely, cells are easily intruded by setting the permeability to $1.48 \cdot 10^{-8} \text{ m}^2$ (150 centidarcy) or more. However, if the permeability exceeds $78.96 \cdot 10^{-8} \text{ m}^2$ (8000 centidarcy), cells are easily intruded but a problem concerning strength arises. Also, cells once intruded are not fixed and are easily flown out. The permeability is preferably $5.92 \cdot 10^{-8} \text{ m}^2$ (600 centidarcy) or more and $49.35 \cdot 10^{-8} \text{ m}^2$ (5000 centidarcy) or less and particularly preferably $9.87 \cdot 10^{-8} \text{ m}^2$ (1000 centidarcy) or more and $19.74 \cdot 10^{-8} \text{ m}^2$ (2000 centidarcy) or less.
- 20 [0015] The pore ratio is preferably 50% or more and 90% or less and particularly preferably 65% or more and 85% or less.
- [0016] It is necessary that the ceramics have a proper amount of pores and moderate permeability (excessive flow is rather undesirable) to allow cells to be intruded and fixed.
- 25 [0017] A human cell is around $10 \mu\text{m}$ in size and therefore the pore 1 provided with the communicating hole 2 having a size of $5 \mu\text{m}$ does not contribute to the fixation of the cell. If the communicating hole 2 has a size of about $8 \mu\text{m}$, the cells can somehow intrude into the ceramics. Although the intrusion is not easily done, the cells which intruded into the pores 1 through communication holes 2 having a diameter of as small as $8 \mu\text{m}$ or more and $20 \mu\text{m}$ or less tend to stay relatively longer than those which intruded into the pores 1 through communication holes 2 having a diameter of $20 \mu\text{m}$ or more. The inside face (inner wall surface) of the pores is formed of calcium phosphate type sintered body to which cells find easy to attach. Therefore, cells are able to stay therein for a long time such that the attachment of such cells to the inside face of the pores is prompted such that the fixation thereof within the pores tend to result.
- 30 [0018] In case where there is, particularly, a space having a size several times to tens of times the size (length dimension) of a cell, the cell strongly tends to be fixed easily. Therefore, if the range of the diameter D_2 of the communicating hole is designed to be around $10 \mu\text{m}$, this is very advantageous in the fixation of the cells.
- 35 [0019] In this way, the communicating hole 2 less than $8 \mu\text{m}$ in size has a particular difficulty in the intrusion of the cells whereas if the size of the communicating hole 2 exceeds $20 \mu\text{m}$, the cells once intruded into the pore 1 tend to flow out again. Therefore, an appropriate control during the manufacturing process such that the pores have preferable dimensions will increase the efficiency of the cell fixation therewithin.
- 40 [0020] Thus, according to an embodiment of the invention the proportion of the volume of the pores 1 communicated with a communicating hole diameter D_2 of $8 \mu\text{m}$ or more and $20 \mu\text{m}$ or less in size be 2% or more and 18% or less of the whole pore volume in terms of cumulative volume percentage (requirement (i)). This reason is that when the proportion is less than 2%, the proportion of the hole 1 to which the cells are firmly fixed becomes too small and therefore the holes cannot contribute to the fixation of the cells, whereas when the proportion exceeds 18%, the proportion of the holes 1 into which the cells can be intruded with difficulty becomes too large (this implies that almost all the pores are associated with communicating holes having a hole diameter of $8 \mu\text{m}$ or more and $20 \mu\text{m}$ or less which is a diameter of a hole into which the cells can be inherently scarcely intruded), so that the intrusion of the cells requires more time, and also, when the proportion exceeds 18%, the quantity (proportion) of the pore 1 having a large communicating hole 2 is decreased with the result that a fluid containing nutrients and the like cannot be extended all over the whole of the calcium phosphate type sintered body. A preferable range of the proportion is 3% or more and 15% or less.
- 45 [0021] It is to be noted that the relation, meant in the present invention, between the volume of pores having a pore diameter D_2 of $8 \mu\text{m}$ or more and $20 \mu\text{m}$ or less and the volume of all pores may be found from the data measured using a mercury porosimeter.
- 50 [0022] In the present calcium phosphate type porous ceramics having a permeability of $1.48 \cdot 10^{-8} \text{ m}^2$ or more and $78.96 \cdot 10^{-8} \text{ m}^2$ or less (150 centidarcy or more and 8000 centidarcy or less) and a volume of the pores communicated with the communicating portion 2 having $8 \mu\text{m}$ or more and $20 \mu\text{m}$ or less is 2% or more and 18% or less of the volume of all pores, the cells are easily intruded into the whole of the ceramics for in vivo use and also the cells once intruded

are firmly fixed.

[0022] The ceramics for in vivo use according to the present invention is desirably an aggregate of a large number of (many) pores 1 each having a relatively uniform size and is also desirably an aggregate of the pores 1 each having a shape close to a globular form, wherein adjacent pores 1 are communicated with each other in such a manner as to allow the whole body to have permeability. The pore having an almost globular form contributes to an improvement in strength. Given as a method of the production of such a porous body are a method in which flammable globular beads and the like are added to a calcium phosphate type rawmaterial, which is then molded under pressure and the beads are burned out during sintering and a method in which a slurry containing a calcium phosphate type raw material is made and is then stirred with controlling the viscosity of the slurry and air cells are introduced into the slurry, which is then sintered while keeping the foaming state. The latter method is preferable because the permeability is easily controllable.

[0023] Also, the pore having a communicating hole diameter D_2 of 8 μm or more and 20 μm or less which is a diameter of a pore in which cells are easily fixed are obtained as a globular one and the latter method is therefore preferable also in this point.

[0024] According to another embodiment of the invention, as shown in Fig. 2, the ceramics for in vivo use has a structure in which globular pores 1a each having its own diameter of 8 μm or more and 15 μm or less exist and the volume of these pores is 0.5% or more and 15% or less of the volume of the whole pores (requirement (ii)). Specifically, small pores 1a are formed cavity-wise on the inner surface of a relatively large pore 1 and each own diameter of these small pores 1a is 8 μm or more and 15 μm or less which is close to the size of a cell. The size of the inlet of each pore 1a may be either slightly narrow or the same as the pore diameter of the pore 1a. A cell is tightly fitted in the pore 1a and easily stabilized. Also, the pore 1a faces the large pore 1. This is convenient to take in nutrients and the like. To say in other words, (plural) small pores 1a are arranged small-cavity-wise on the inside peripheral surface of each of the large pores 1 and the diameter of the pore 1a is set to 8 μm or more and 15 μm or less.

[0025] Also in the structure explained in Fig. 2, the permeability (transmittance) is designed to be $(1.48 \cdot 10^{-8} \text{ m}^2$ (150 centidarcy) or more and $78.96 \cdot 10^{-8} \text{ m}^2$ (8000 centidarcy) or less. This ensures that cells are easily intruded into the whole of the ceramics for in vivo use and the cells once intruded are firmly fixed.

[0026] The present invention is not limited to the aforementioned embodiments. The ceramics of the present invention may be either combined with other dense members or may contain active materials in the surface of the pore or the calcium phosphate type ceramics itself.

EXAMPLES

(Examples 1 to 5 and Comparative Example 1)

[0027] Six members (six types) for in vivo use which were produced by stirring and foaming and made of hydroxyapatite were prepared in the following production method.

[0028] First, a hydroxyapatite powder having an average particle diameter of 1 μm or less, ion exchange water which was a dispersion medium and polyethylenimide which was a cross linking polymerizable organic material were compounded in a ratio by weight of 10:8:1 and these components were mixed for 10 hours using a ball mill to prepare a slurry.

[0029] A nonionic surfactant was added to this slurry, which was then mechanically stirred to incorporate air cells into the slurry. The intensity and speed of the stirring and the amount of the surfactant to be added at this time were varied to prepare different six slurries.

[0030] An epoxy compound as a crosslinking agent was added to each slurry to be followed by stirring and then the mixture was poured into a mold. After the mixture was solidified by crosslinking polymerization and then released from the mold, followed by drying and calcinating at 1200 °C.

[0031] The resulting calcined body was divided into plural products, which were then molded and thereafter washed.

[0032] Each resulting member in vivo use was measured by a mercury porosimeter to find the condition of pores and also the permeability of each member was measured according to ASTM C577-68.

[0033] Thereafter, each member was embedded in the femur of a rabbit and taken out after two weeks and six weeks respectively to observe the state of cells.

[0034] If the permeability was $1.48 \cdot 10^{-8} \text{ m}^2$ (150 centidarcy) or more, particularly $1.87 \cdot 10^{-8} \text{ m}^2$ (190 centidarcy) or more, cells were intruded effectively. On the other hand, members for in vivo use which had a permeability exceeding $78.96 \cdot 10^{-8} \text{ m}^2$ (8000 centidarcy), particularly, $98.7 \cdot 10^{-8} \text{ m}^2$ (10000 centidarcy) were broken before and after the experiment. Although it was thought that cells are easily intruded, the members were not practical.

(Comparative Examples 1 to 3)

[0035] With regard to calcium phosphate type members for in vivo use which were manufactured by A company, the

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permeability of each member was measured, to find that each permeability was all less than $0.99 \cdot 10^{-8} \text{ m}^2$ (100 centidarcy). Also, with regard to calcium phosphate type members for in vivo use which were manufactured by B company, the permeability of each member was measured, to find that each permeability was all less than $1.48 \cdot 10^{-8} \text{ m}^2$ (150 centidarcy). Each member was embedded in the femur of a rabbit and taken out after two weeks and six weeks respectively to observe the state of cells. The quantities of fixed cells obtained after two weeks and six weeks were each one-half of those of the member of the present invention. The proportion of pores having a pore diameter of $8 \mu\text{m}$ or more and $20 \mu\text{m}$ or less to all pores was 30% or more in the case of the member of A company and 20% or more in the case of the member of B company.

[0036] With regard to the foregoing Examples 1 to 5 and Comparative Examples 1 to 3, each permeability, proportion of the volume of pores and result of the experiment (observation) are shown in the following Table 1.

[Table 1] RESULT OF EXPERIMENT

	Permeability (10^{-8} m^2 (centidarcy)), 1 atm, 25°C N_2 gas	Proportion of the volume of pores having a communicating hole diameter of $8 \mu\text{m}$ or more and $20 \mu\text{m}$ or less to the volume of all pores (%)	Easiness of intrusion of an organization of a living body after two weeks	Formation of a myeloid tissue after tissue after 6 weeks
Comparative Example 1	98.7 (10000)	5	Δ	Δ
Example 1	69.1 (7000)	5	◎	◎
Example 2	39.5 (4000)	8	◎	◎
Example 3	12.8 (1300)	10	○	○
Example 4	6.42 (650)	10	○	○
Example 5	1.87 (190)	13	○	○
Comparative Example 2	0.99 (100)	24	×	×
Comparative Example 3	0.49 (50)	35	×	×

◎:Very good

○:Good

Δ:Practical

×:Unpractical

[0037] Next, with regard to the following Example 6 and Comparative Example 4, the same experiment was made. The results of the experiment are shown in Table 2.

(Example 6)

[0038] One member for in vivo use which was produced by stirring and foaming in the same manner as in the above Example and made of hydroxyapatite was prepared to measure the diameters of the pores in the member. Said measurement was done by bodily embedding the member for in vivo use within the resin and subjecting the same to a microscopic observation after grinding the same. Further, the image of the pores was analyzed to correct from a two dimensional aspect to a three dimensional one in accordance with the Johnson-Saltokov method to find the ratio of the volumes of pores having a size of 8 to $15 \mu\text{m}$. Then, the permeability of the member was measured according to ASTM C577-68.

(Comparative example 4)

[0039] Also, a slurry containing hydroxyapatite was applied to an urethane foam, which was then punched by burning to obtain a sample of Comparative Example.

[Table 2] RESULT OF EXPERIMENT

	Permeability (10^{-8} m ² (centidarcy)) 1 atm, 25°C N ₂ gas	Proportion of the volume of pores itself having a pore diameter of 8 µm or more and 15 µm or less(%)	Easiness of intrusion of an organization of a living body after two weeks	Formation of a myeloid tissue after 6 weeks
Example 6	1.87 (190)	2	○	○
Comparative Example 4	86.86 (8800)	0.01	Δ	Δ
◎: Very good ○: Good Δ: Practical ×: Unpractical				

[0040] Next, a sample (a cylindrical body having a diameter of 30 mm and a height of 10 mm formed from hydroxyapatite having a porosity of 75 %) similar to one in Example 3 was subjected to measurement in the following condition: pressure difference: 620 mm H₂O and 24 to 34 °C, to find that the amount of permeated water was 105 (cc/cm²·min).

[0041] If the permeability is kept within the range of from 16 (cc/cm² · min.) up to 600 (cc/cm² · min.), the intrusion of liquids is facilitated such that nourishments for cells are preferably carried thereto.

[0042] It is to be noted that the permeability can be measured according to the method as described in Japanese Patent Publication No. H4-77609.

Claims

- Calcium phosphate type porous ceramics for in vivo use, comprising pores (1), (1a) having an almost globular form, which are contacted and communicated with each other so that the ceramics has a permeability of 1.48×10^{-8} to 78.96×10^{-8} m² (150-8,000 centidarcy), measured according to ASTM C577-68, and the ceramics further complies with either one or both of the following two requirements:
 - the volume of the pores (1) communicated with a communicating portion (2) having a hole diameter (D₂) of 8-20 µm is 2-18% of the volume of all pores.
 - the volume of the pores (1a) having a pore diameter of 8-15 µm is 0.5-15% of the volume of all pores.
- Calcium phosphate type porous ceramics of claim 1, wherein both requirements (i) and (ii) are fulfilled.

Patentansprüche

- Poröse Keramik vom Calciumphosphattyp zur Verwendung in vivo, umfassend Poren (1), (1a) mit einer nahezu globularen Form, die miteinander kontaktiert und in Verbindung gesetzt sind, so dass die Keramik eine Permeabilität von $1,48 \times 10^{-8}$ bis $78,96 \times 10^{-8}$ m² (150-8.000 centidarcy), gemessen entsprechend ASTM C577-68, aufweist und dass die Keramik weiterhin eine oder beide der folgenden beiden Erfordernisse erfüllt:
 - das Porenvolumen (1), das mit einem kommunizierenden Bereich (2) mit einem Lochdurchmesser ((D₂) von 8-20 µm kommuniziert, ist 2-18% des Volumens aller Poren,
 - das Volumen der Poren (1a) mit einem Poredurchmesservon 8-15 µm ist 0,5-15% des Volumens aller Poren.
- Poröse Keramik vom Caiciumphosphattyp nach Anspruch 1, wobei beide Erfordernisse (i) und (ii) erfüllt sind.

Revendications

5 1. Céramique poreuse de type à base de phosphate de calcium pour une utilisation in vivo, comprenant des pores (1), (1a) ayant une forme pratiquement globulaire, qui sont en contact et en communication les uns avec les autres de sorte que la céramique a une perméabilité de $1,48 \times 10^{-8}$ à $78,96 \times 10^{-8} \text{ m}^2$ (150 - 8 000 centidarcy), mesurée selon ASTM C577-68, et la céramique satisfait en outre l'une ou les deux exigences suivantes :

- 10 (i) le volume des pores (1) en communication avec la partie de communication (2) ayant un diamètre de trou (D_2) de 8 - 20 μm est de 2 - 18 % du volume de tous les pores ;
 (ii) le volume des pores (1a) ayant un diamètre de pore de 8 - 15 μm est de 0,5 - 15 % du volume de tous les pores.

15 2. Céramique poreuse de type phosphate de calcium selon la revendication 1, dans lequel les deux exigences (i) et (ii) sont satisfaites.

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Fig.1

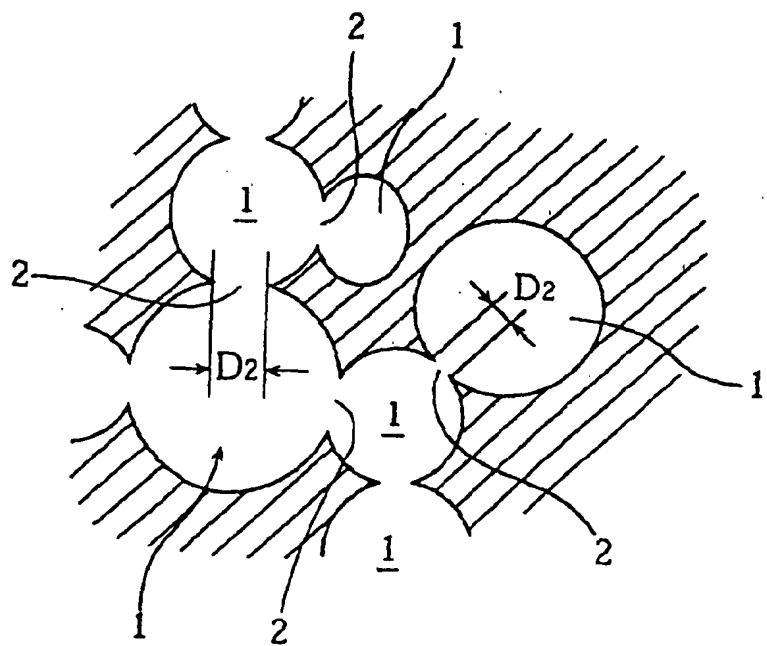


Fig.2

